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(54) Forming re-inforced tubulor structures

(57) In order to increase the stress resistance of composite fiber structures (16) such as rotors and pressure vessels, an inherent compression stress field is established in the matrix material. This is performed by the curing of the matrix material while the fibers (12 - 14) are elastically stretched. In order to extend the application of this method to structures to be used at raised temperatures, fibers with a high strength and a high modulus of elasticity are employed. Carbon fibers of the intermediate type are particularly well suited. Owing to the lesser stretch of such fibers even under a high stress, the strain on the matrix material is less so that the stretch may be kept below the elongation of the matrix material, even if the material is thermally stable and is accordingly relatively brittle.

Fig. 1

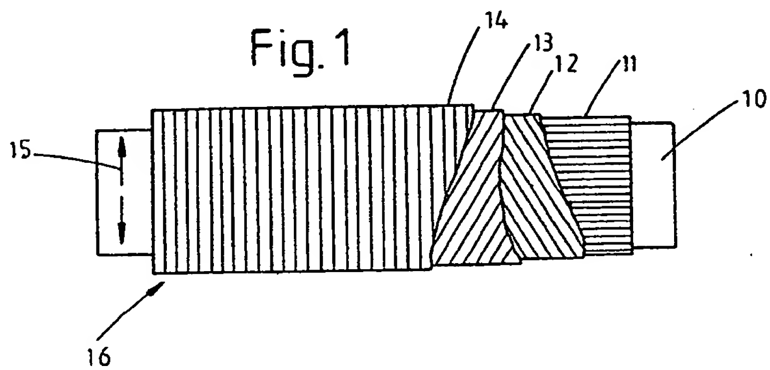

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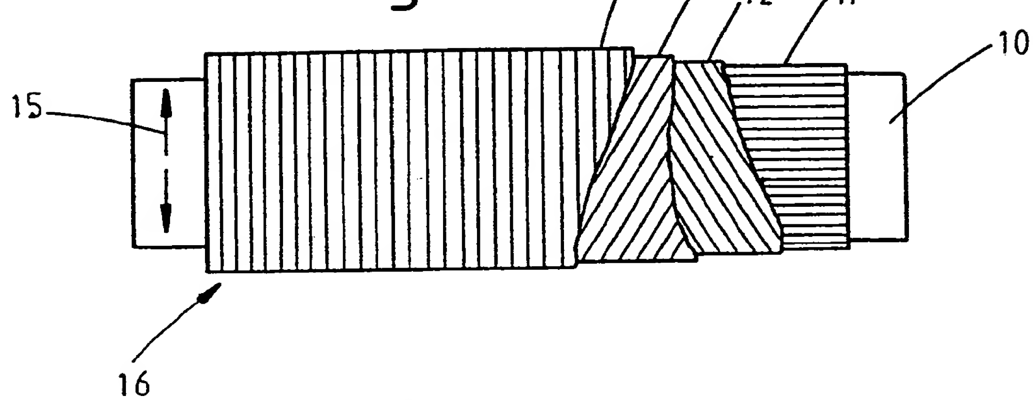
Fig. 1



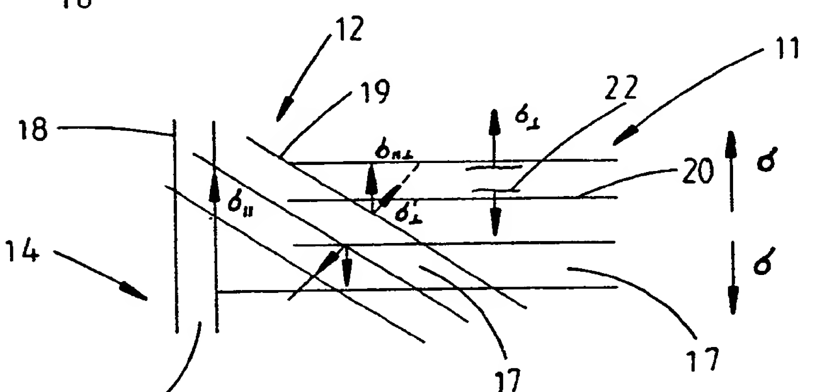


Fig. 2

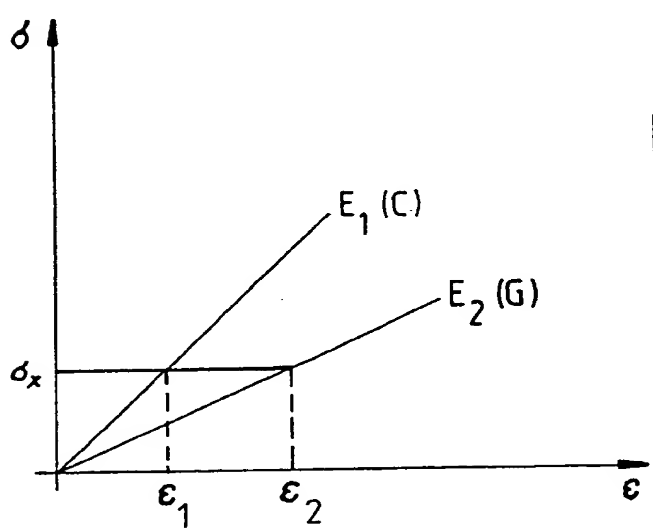


Fig. 3

SPECIFICATION

A method of manufacturing a tube

The invention relates to a method for the manufacture of a tube, such as a rotor tube, of fibers embedded in a matrix material, wherein the fibers are wound onto a mandrel, which is then expanded radially and wherein the matrix material is then cured while the fibers are in a stretched state.

Rotor tubes made of fiber reinforced composite material are usually made with a plurality of fiber plies with different alignments. The fibers wound onto the mandrel may either be endless fibers or in the form of fiber mats. During later operation of the rotor it is more especially tensilely stressed in the peripheral direction. Depending on the different alignment of the fibers these stresses will have different effects in the fiber plies. It has been observed that the plies running athwart the principal stress direction form the weakest point in a composite structure under load, because the tensile strength in a direction normal to the fiber direction is dependent on the relatively low tensile strength of the matrix. In the parts between the fibers cracking is frequent and is likely to spread.

In the British patent application 8,502,475 a proposal has been made to remedy such an undesired effect by causing the matrix material to cure with the fibers in a pretensioned state so that an inherent compression results in the resin which constitutes a sort of reserve stretch capacity. Accordingly the permissible stretch is increased in a direction normal to the fibers.

This method has been proposed for composite glass fiber structures (see the periodical "Kunststoffe" 74th year, 1984, No. 9, pages 520 through 526), in which case ductile matrix materials were used which owing to the increased elongation in operation are able to match the stretch of the glass fibers. However such a scheme is only suitable for applications in which no thermal loads are likely.

One aim of the present invention is to devise a method of the initially noted type such that the resulting composite fiber structures are able to withstand higher temperatures.

In order to achieve this or further objects appearing herein, a method for the manufacture of a tube of fibers embedded in a matrix material, wherein the fibers are wound onto a mandrel, which is then expanded radially and wherein the matrix material is then cured while the fibers are in a stretched state, is performed using fibers with a high strength and a high modulus of elasticity.

The invention is based on the notion that the requirement as regards the elongation of the matrix material may be modified by the selection of the fibers in accordance with the elastic behavior. Owing to the small degree of stretch it is possible to use a more brittle or harder matrix material if the fibers have a higher modulus of elasticity. Such materials have a higher thermal stability, since the elongation is inversely proportional to the thermal stability.

The invention accordingly provides a method with which the available strength of a fiber composite structure may be enhanced, such enhancement being independent of the operating temperature to which the composite structure is to be subjected.

A further advantage of the method is that when producing a composite fiber structure, owing to the high modulus of elasticity of the fibers, a relatively high inherent compressive strain may be introduced into the matrix material with a low degree of stretch.

It has been discovered that carbon fibers of the intermediate or HST type (high strain type) make possible the use of matrix materials with an elongation of 5% or less (in the pure resin molding material). Materials with this degree of strength have a thermal stability of at least up to 100° C. More especially, fibers of the high modulus (HM) type are well suited, which have an even higher strength and elongation than the above noted fibers.

The method of the invention will now be described in more detail with reference to one example thereof as shown in the accompanying diagrammatic drawing.

For the production of pressure tubes or rotor tubes for example, fiber plies 11 to 14 are applied to a radially expandable core 10 either by winding on an endless filament or applying fiber mats. The core 10 is expanded, for example by hydrostatic pressure or by mechanical action and raised to the curing temperature of the matrix used until same is cured.

In this method the fibers extending in the direction of loading, more especially the circumferential fibers of the ply 14, are elastically prestressed.

After relaxing the radial force 15 and during the cooling of the composite tube 16 the stretched fibers will tend to return to their original condition. This contraction is however prevented by the cured matrix material 17. The fibers 18, and more especially the circumferential ply 14 and also the fibers 19 of the 45° plies 12 and 13, therefore retain an inherent tension strain, which exerts a compressive stress on the matrix material 17. This residual inherent compression strain has such an effect that on expanding the tube 16 during use the development of strains in the matrix material 17 is such that when the degree of stretch is low there is firstly a relaxation of the inherent compression strain and it is only after exceeding a larger degree of strain that a tensile strain develops in the matrix material. A tensile stress (σ) acting on the fibers 18 and 19 and on the matrix material 17, as indicated in figure 2, will be resisted by the fibers themselves in the case of the fiber ply 14 parallel to the tensile stress, in which the tensile strength is greatest. In the longitudinal fibers 20 of the ply 11 the case is different inasfar as the tensile stress acts across the fiber direction: σ, and the contribution to resisting the longitudinal stress in this ply is provided by the matrix material 17. This so-called transverse strength is lowest.

If the structure 16 consists of fibers with a low modulus of elasticity, as for example glass fibers

as used in known methods, the tensile stress of for example σ_x will cause a relatively large extension of ϵ_2 (curve E_2 in figure 3). This strain may well exceed the elongation of the matrix material, and there will be cracking between the fibers 22 despite the reserve stretch.

However if fibers 18 to 20 are used which have a high tensile strength and a high modulus of elasticity, as for example in curve E_1 in figure 3, the same tensile stress σ_x applied to the composite structure will produce a smaller degree ϵ_1 of stretch or extension. Fibers that are particularly satisfactory in this respect are carbon fibers of the intermediate type, which have a modulus of elasticity of 295 GPa and a tensile strength of up to 5100 N/squ. mm. Furthermore carbon fibers of the types HST or HM may be used (see Kunststofftechnik, VDI Verlag, pages 167 through 169).

In connection with these fibers it is possible to use a resin based on diglycidylether-bisphenol A with diamino diphenylsulfone as a curing agent. Such matrix material has a thermal stability of up 100° C.

A further suitable matrix material with an elongation under 5% is a resin based on diglydidylether-bisphenol A with methyltetrahydro-phthalic anhydride with or without N-methylimidazole as a diluent.

In connection with fibers - as for example amounting to 60% by volume - the available elongation is only about 10% of the elongation of the pure matrix material, i.e. the available elongation of the above mentioned materials is reduced to about 0.5%. In the case of such materials the provision of reserve stretch is particularly valuable but only serves a useful purpose if the fibers have a sufficiently high modulus of elasticity. Carbon fibers as mentioned produce an excellent combination for highly stressed structures where good thermal stability is required.

CLAIMS

1. A method for the manufacture of a tube made up of fibers embedded in a matrix material, wherein the fibers are placed on a mandrel, which is then expanded radially and wherein the matrix material is then cured while the fibers are in a stretched state, said method being performed using fibers with a high strength and a high modulus of elasticity.

2. A method as claimed in claim 1 wherein said matrix material is thermally stable.

3. A method as claimed in claim 1 or claim 2 wherein said fibers include carbon fibers.

4. A method as claimed in any one preceding claim wherein said fibers include carbon fibers of the intermediate or high strain type.

5. A method as claimed in claim 4 wherein said matrix material is formed by reacting two components to form an epoxy resin.

6. A method as claimed in claim 5 wherein one of said components is diglycidyether.

7. A method as claimed in claim 5 wherein one of said components is bisphenol A.

8. A method as claimed in claim 5 wherein one of said components is diamino-diphenyl-sulphone.

9. A method as claimed in claim 5 wherein one of said components is methyltetrahydro-phthalic anhydride.

10. A method as claimed in any one of claims 5 to 9 in which N-methylimidazole is used as a diluent.

11. A method as claimed in any one of the preceding claims wherein said fibers include fibers of the high modulus type.

12. A method as claimed in any one preceding claim wherein said fibers are in the form of an endless fiber wound onto said mandrel.

13. A method as claimed in any one of claims 1 to 11 wherein said fibers are in the form of fiber mats.

14. A method as claimed in claim 1 substantially as described herein with reference to the accompanying drawing.

15. A tube structure produced by the method as claimed in any one of the claims 1 to 14.

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